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Numerical Modeling of Welding Arc with Complex System between Arc Plasma and Molten Electrode

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Abstract. It is important to consider the interaction between arc plasma and electrodes because melting of electrodes strongly affects arc plasma. Therefore, a GMA model will be developed, based on the unified model of TIG arc. As a first step, a TIG arc model with a calculation for molten cathode shape has been proposed. This model is calculated in two cases; molten W cathode and Calculation result of W cathode. In the case of W cathode, cathode shape change was found to affect the arc plasma property strongly. Calculated results of radial temperature distributions on electrode surface and arc pressure distributions at the anode surface are very similar to the experimental results.

Introduction

Many researchers have studied numerical modeling of welding arc. The authors have also investigated unified model of TIG arc [1]. Recently Hirata [2] and Fan [3] has developed models of GMA, which include melting of wire electrode, growth of droplet and metal transfer. It is significantly important to consider the interaction between the arc plasma and electrodes because melting of electrodes strongly affect arc plasma property.

Therefore, a GMA model, based on the unified model of TIG arc, will be developed. As a first step, a TIG arc model with a calculation for melting cathode shape has been proposed. Fig.1 shows the shapes of W cathode and W-2% ThO_2 cathode. Pure W cathode is easy to melt because its work function is larger than that of W-2% ThO_2 cathode [4]. In this paper, plasma property has been calculated with molten cathode.

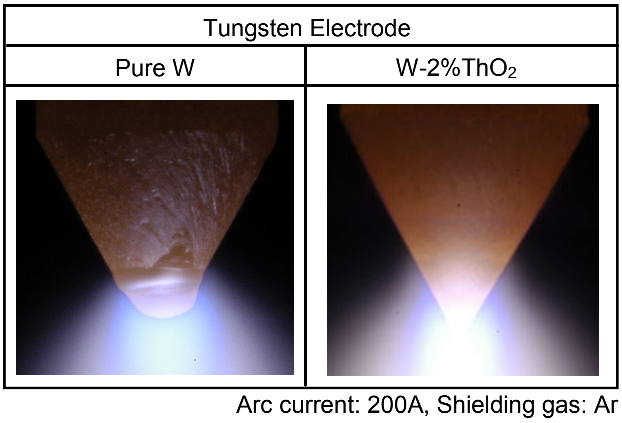

Fig. 1 Shapes of W cathode and W-2% ThO_2 cathode.

Simulation model

The tungsten cathode, the arc plasma and the water-cooled copper anode are described in a frame of cylindrical coordinate with axial symmetry around the arc axis. The diameter of the tungsten cathode is 3.2 mm with a 60 degrees conical tip. The anode is 50 mm in diameter and 10 mm in thickness. The electrode gap is set to be 5mm. The arc current is set to be 200 A. Ar gas is introduced at a flow rate of 10 L/min from the outside of the cathode on the upper boundary. The flow is assumed to be laminar, and the arc plasma is assumed to be under the local thermodynamic equilibrium (LTE). The other numerical modeling methods are given in detail in previous papers [5, 6]. The differential equations (1)-(6) are solved iteratively by the SIMPLEC numerical procedure [7]:

Mass continuity equation;

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r)+\frac{\partial}{\partial z}(\rho v_z)=0 \tag{1}$$

Radial momentum conservation equation;

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\rho v_r^2\right)+\frac{\partial}{\partial z}(\rho v_r v_z)=-\frac{\partial P}{\partial r}-j_z B_\theta+\frac{1}{r}\frac{\partial}{\partial r}\left(2r\eta\frac{\partial v_r}{\partial r}\right)+\frac{\partial}{\partial z}\left(\eta\frac{\partial v_r}{\partial z}+\eta\frac{\partial v_z}{\partial r}\right)-2\eta\frac{v_r}{r^2} \tag{2}$$

Axial momentum conservation equation;

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_z)+\frac{\partial}{\partial z}\left(\rho v_z^2\right)=-\frac{\partial P}{\partial z}+j_r B_\theta+\frac{\partial}{\partial z}\left(2\eta\frac{\partial v_z}{\partial z}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(r\eta\frac{\partial v_r}{\partial z}+r\eta\frac{\partial v_z}{\partial r}\right) \tag{3}$$

Energy conservation equation;

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r h)+\frac{\partial}{\partial z}(\rho v_z h)=\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{r\kappa}{c_p}\frac{\partial h}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{\kappa}{c_p}\frac{\partial h}{\partial z}\right)+j_r E_r+j_z E_z-R \tag{4}$$

Current continuity equation;

$$\frac{1}{r}\frac{\partial}{\partial r}(rj_r)+\frac{\partial}{\partial z}(j_z)=0 \tag{5}$$

Ohm's law;

$$j_r=-\sigma E_r,\ j_z=-\sigma E_z \tag{6}$$

where h is enthalpy; P is pressure; v_z and v_r are the axial and radial velocities; j_z and j_r are the axial and radial component of the current density; g is the acceleration due to gravity; κ is the thermal conductivity; C_p is the specific heat; ρ is the density; η is the viscosity; σ is the electrical conductivity; R is the radiation emission coefficient; E_r and E_z are the radial and axial components of the electric field defined by $E_r = -\partial V/\partial r$ and $E_z = -\partial V/\partial z$, respectively, where V is electric potential. The azimuthal magnetic field B_θ induced by the arc current is evaluated by maxwell's equation.

$$\frac{1}{r}\frac{\partial}{\partial r}(rB_\theta)=\mu_0 j_z \tag{7}$$

Where μ_0 is the permeability of free space.

In the solution of Eqs. (1)-(6), special account needs to be taken at the electrode surface for effects of energy that only occur at the surface. At the cathode surface, additional energy flux terms need to be included in Eq. (4) for thermionic cooling due to the emission of electrons, ion heating, and radiation cooling. The additional energy flux for the cathode H_k is:

$$H_K=-\varepsilon\alpha T^4-|j_e|\phi_K+|j_i|V_i \tag{8}$$

Where ε is the surface emissivity; α is the Stefan-Boltzmann constant; ϕ_K is the work function of the tungsten cathode; Vi is the ionization potential of argon; j_e is the electron current density; j_i is the ion current density. At the cathode surface, for thermionic emission of electrons, j_e cannot exceed the Richardson current density j_R [8] given by:

$$|j_R| = AT^2 \exp\left(-\frac{e\phi_e}{k_B T}\right) \quad (9)$$

Where A is the thermionic emission constant for the cathode surface; ϕ_e is the effective work function for thermionic emission of the electrode surface at the local surface temperature; k_B is the Boltzmann's constant.

Eq. 7 [9] is applied to this model for estimating molten cathode shape.

$$\gamma(r_{zz} / (1 + r_z^2)^{3/2}) = \rho g z - \lambda \quad (10)$$

Where r is radial position; z is axial position; γ is surface tension; λ is Lagrange multiplier, $r_z = \partial r / \partial z$, $r_{zz} = \partial^2 r / \partial z^2$.In this equation, only the gravity and surface tension are considered as the forces to molten liquid surface. And the condition is given that the volume of molten cathode area does not change after the calculation.

Result and discussion

Fig. 2 and Fig. 3 show calculated results of temperature fields and velocity fields in two cases; molten W cathode and non-molten W-2% ThO_2 cathode. These calculations are made for the steady state. In the case of W-2% ThO_2 cathode, it is seen that the maximum temperature of cathode is more than 3500 K, maximum temperature of arc plasma is 19000 K and maximum velocity of cathode jet is 250 m/s. The reason for it is that the tip is sharp, so, the arc current is concentrated. On the other hand, in case of W cathode, it is seen that the maximum temperature of cathode is 4100 K, maximum temperature of arc plasma is 15000 K and maximum velocity of cathode jet is 109 m/s. The reason for it is that the tip is round, so, the arc current is not so concentrated. It is obvious that the change of cathode shape affects the arc plasma property strongly.

Fig.4 shows calculated results of radial temperature distributions on electrode surface. The maximum temperatures of cathode are 4079 K, 3776 K for W and W-2% ThO_2, respectively. These are in agreement with experimental results conducted by Haidar and Farmer [8].

Fig.5 shows calculated results of arc pressure distributions at the anode surface. The maximum arc pressure for W is drastically lower than that for W-2% ThO_2. Sadek measured arc pressure distributions at a water-cooled copper anode by a semiconductor transducer [9]. His experimental results are very similar to the authors' predictions.

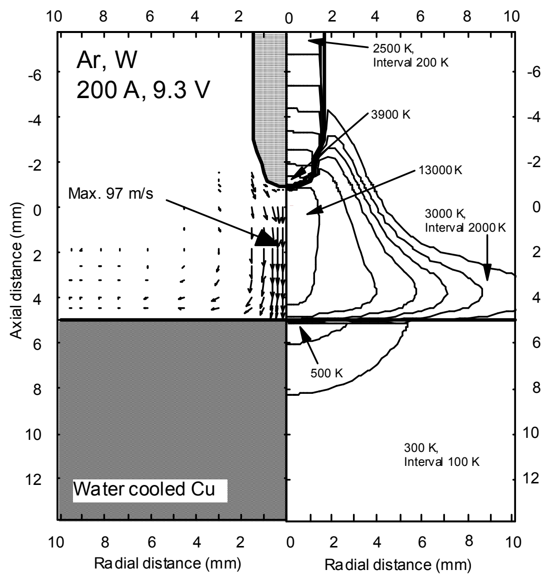

Fig. 2 Calculated results of temperature field and velocity field for W cathode.

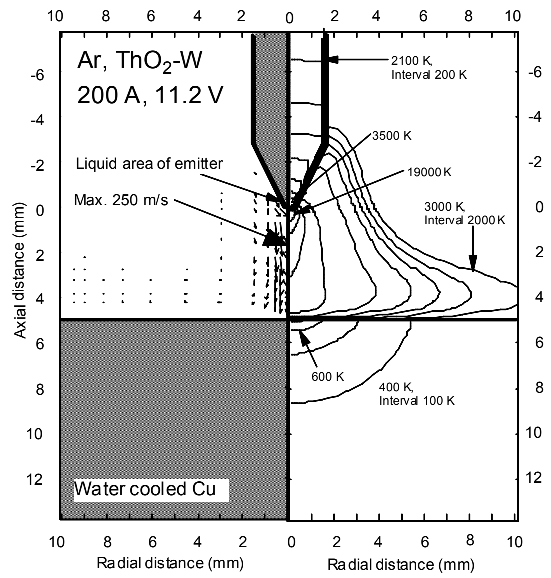

Fig. 2 Calculated results of temperature field and velocity field for W-2% ThO_2 cathode.

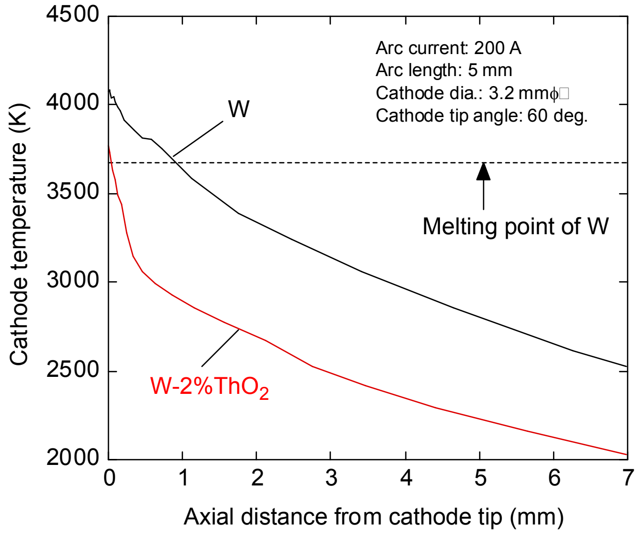

Fig. 4 Calculated results of radial temperature distributions on the cathode surface

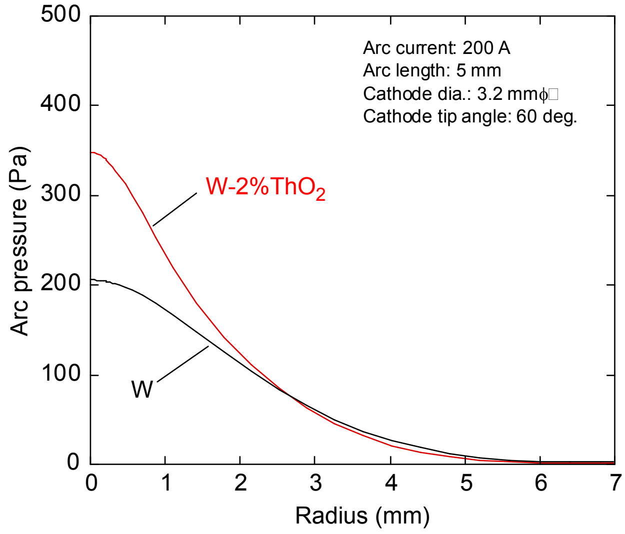

Fig. 5 Calculated results of arc pressure distributions at anode surface.

Summary

In this paper, a TIG arc model, is proposed, with a calculation for molten cathode shape based on the unified model of TIG arc. Calculated results of temperature fields and velocity fields for molten W cathode and non-molten W-2% ThO_2 cathode were shown. It was obvious that change of cathode shape affected the arc plasma property strongly. Temperature distributions of the cathode surface and arc pressure distributions at the anode surface were numerically analyzed. Temperature distributions were in agreement with the experimental results. The maximum arc pressure for W is drastically lower than that for W-2% ThO_2.

References

[1] M. Tanaka, M. Ushio and J.J. Lowke: JSME Int. J. Series B Vol. 48-3 (2005), p. 397-404.

[2] Y. Hirata, K. Ohnishi and T. Ohji: Numerical Model of Gas shielded Metal Arc Plasma with Metal Transfer, PREPRINTS OF THE NATIONAL MEETING OF J.W.S. NO.77 AUTUMN (2005), p. 80 (in Japanese).

[3] H.G. Fan and R. Kovacevic: J. Phys. D: Appl. Phys. Vol. 37 (2004), p. 2531-2544.

[4] M. Tanaka, M. Ushio, M. Ikeuchi and Y. Kagebayashi: J. Phys. D: Appl. Phys. Vol. 38 (2005), p. 29-35

[5] M. Tanaka, H. Terasaki, M. Ushio and J.J. Lowke: Metall. & Mater. Trans. A, Vol. 33A (2002), p. 2043-2052.

[6] M. Tanaka, H. Terasaki, M. Ushio and J.J. Lowke: Plasma Chem. & Plasma Process. Vol. 23 (2003), p. 585-606.

[7] T. Ohji: *Introduction of Welding Processes, First edition*, SANPO PUBLICATIONS INC, Tokyo (1996) (in Japanese).

[8] J. Haidar and A.J.D. Farmer: J. Phys. D: Appl. Phys. Vol. 28 (1995), p. 2089-2094.] A.A. Sadek, M. Ushio and F. Matsuda: Metall. & Mater. Trans. A, Vol. 21A (1990), p. 3221-3236.

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